The Effect of Research and Development Investment on Patents

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Abstract

Economists today mostly assume that investment results in gains for that particular field. In this paper, we test for the effect investment in research and development (R&D) has on technological growth. We utilize cross sectional data from 2010 and test a variety of other factors including Gross Domestic Product (GDP) per capita; average years of education; export volume into the United States; and the Leamer Index, a measurement for natural resource abundance in a country. The results from the experiment show that the R&D Expenditure has a significant effect on number of patents filed. In addition, whether or not a country was developed was found to significantly influence the number of patents filed. The various other variables including: average years of education, GDP per capita, and the Leamer Index were found to be insignificant while the exports to the US were found to have a significant effect on patents filed.

1. Introduction

"*Ever since the Industrial Revolution, investments in science and technology have proved to be reliable engines of economic growth. If homegrown interest in those fields is not regenerated soon, the comfortable lifestyle to which Americans have become accustomed will draw to a rapid close." (Tyson).* From the time of early civilization, technology was an essential aspect for the advancement of humanity. Technology immensely increased efficiency. For example, through the invention of the printing press, books could be mass produced at greater speeds than ever before and the conception of the computer allowed humans to more quickly and effectively generate and implement ideas. Technology also increased the ability for mankind to sell products to those that most demanded it - serving as an enforcement to economic supply and demand. An example of where this occurred is through the invention of the wheel, allowing quicker and easier transportation and through the invention of online retailers, allowing producers to reach out to consumers more easily. The lowering of costs to producers is yet another benefit to technological growth. Machines can often accomplish more in less time than humans while being less error prone. Through these and various other positive benefits, technology is essential to economic growth. As such, the measurement of technological growth is essential to understanding the causes of technological growth so government can better implement policies that most effectively stimulate technological advancements.

This research paper discusses the correlation between technology and a variety of other independent variables. The dependent variable is the growth in patents filed by country, an indicator for technological growth. The hypothesis is that there is a positive correlation between investment in technology and growth in technology. This is supported through the paper, *What Determines Patents per Capita in OECD Countries?* (Falk), and through economic reasoning. In the journal article, it is stated that an increase in investment in technology leads to improvements in technology. From an economic perspective, investments in almost anything results in gains for that area. Technology is no exception. With an increase in investment in technology, a growth in technology can be expected.

A preliminary look at the data supports the initial hypothesis that there is a positive correlation between growth in technology and investment in technology. In addition, there seems to be a positive correlation between patents filed and exports to the US, education, and natural resources, however the latter two variables do not seem to be as clear and could potentially be insignificant upon further tests. In the other set of data, there seems to be positive correlations between R&D Expenditures and GDP per capita, exports into the US, and natural resource abundance. There seems to be no correlation at all to education and the correlations between GDP and natural resources is small and could potentially be found to be insignificant.

2. Literature Review

Technology progress is a central topic in development economics because it captures the source of continued growth in economies. Solow concludes that all the long-term economic growth is caused by population and technological growth (Solow). Thus, how technology progresses is determined as vital to help us understand the development of countries.

2.1. Romer Model

Various endogenous growth models have included the mechanism of technology progress. Romer proposed that in the R&D sector, the growth rate of technology is proportional to the current level of technology and the labor input in technological development (Segestrom):

$$\frac{d}{dt}A = \eta AL$$

In the Romer model, a constant return is assumed and thus a constant or even increasing growth rate of technological progress can be derived.

However, empirical evidence shows that the total factor of production (TFP) doesn't increase over time when labor input in the R&D sector increases. Jones has modified the Romer model in such a way that decreasing return is present (Jones). However, as Bosch and his colleagues have pointed out, the diminishing return on labor can be high (Segestrom) and R&D efforts can be redundant (Kortum). As a result, the observation on TFP can be misleading.

To avoid such problems, different proxies are used to measure technology progress. The selection of a proxy is controversial. Shanks and Zheng used capitalized R&D expenditure as a measure of technology (Shanks). Loo utilized R&D expenditure as the proxy (Loo). Scherer considered the number of patents a better proxy compared to R&D Expenditures from his research efforts (Scherer).

2.2. Zhang Model

The models using patent as the proxy have been extensively studied. Zhang (2011) built his model as below:

$$P_{it} = \delta H_{it}^{\alpha} R_{it}^{\beta} P_{it}^{\varphi}$$

$$ln\, P_{it} = ln\, \delta + \alpha\, lnH_{it} + \beta\, lnR_{it} + \varphi\, lnP_{it} + \varepsilon_{it}$$

where P represents the number of patents during year t, H represents the human capital during year t, R represents R&D expenditure and P represents the cumulative stock of patents. The ordinary least square (OLS) analysis shows significant positive relation between the cumulative stock of patents and the number of patent applications. The model given in this paper seems to be fairly modern and is widely used, however the following model is more widely used and will be the base model used in the paper.

2.3. Bosch Model

The model proposed by Bosch (Bosch) is:

$$ln\ P_{it} = \beta\ ln\ R\&D_{it} + \gamma_1\ ln\ US_{it} + \gamma_2\ ln\ LI_{it} + \alpha_{it} + \varepsilon_{it}$$

where P is the number of patents filed in the US during year t, R&D is the R&D expenditure, US is the export volume of each country to the US, LI is the Leamer Index of natural resource abundance and α_{it} captures country specific fixed effects.

In his regression analysis, GDP per capita, intellectual property right protection and institutional collaboration are considered to capture the country specific factors. The regression for OECD countries shows positive relations between the number of patent applications and GDP per capita.

One contribution of this paper is add a variable to the Bosch model. The variable is education. Intuitively, an increase in education increase the number of patents filed in the country. This is due to the fact that the a majority of patents result from research and research is predominantly filled with people who have gone through higher education. In addition to this, more updated data is utilized than in the paper from the World Bank Database.

3. Data

In order to measure technology in each country, the number of patents filed in the country was utilized. The economic backing for utilizing the patents filed as a dependent variable is given in *The Impact of Technology on Economic Growth* (Loo). The *OECD Science, Technology, and Industry Outlook* also supports the use of patents as the dependent variable depending on technology investment (OECD). The backing for utilizing the numbers of patents filed per country is also given in *Patenting and R&D: A Global View* (Bosch). In the article, it is stated and shown that there is a strong positive correlation between number of patents filed and technological growth, however there could potentially be decreasing returns to scale. Because of this, the log of patents is used as the dependent variable to account for the decreasing returns to scale. Since there are different office of patents across the world, we chose to use the patent applications filed in the US since the US has the most patents filed and, as a result, would better represent more countries. The main independent variable used is investment in technology. Other independent variables used for the multiple regression analysis include: GDP per capita, the export volume to the United States, human capital, and the Leamer Index (LI). Technology investment is described by R&D expenditure. It is a very important variable in determining growth in technology as higher investment tends to yield greater growth in that area. The proxy used for human capital is the average years of education. LI, by definition, is the net export volume of raw materials. It is calculated by summing the net export volume of fuel and that of ore and metals. The purpose for including US exports is due to the fact that countries exporting into the US have a higher incentive to apply for patents in the US to protect their technology. Thus the number of patent applications filed to the US is expected to increase. Human capital is expected to generate more technological progress because it increases the productivity of the R&D sector. In order to measure the human capital of each country, we adopt the standard proxy which is the average years of education. Leamer Index (LI) measures the natural resource abundance of a country. It is defined as the net export of raw materials per worker. The abundance of natural resources can lead to comparative advantage and may stimulate technological progress in various fields, as Bosch's research shows. We calculate the net export of raw materials by adding the net export of fuel and that of ore and metal.

The data for the the patents filed per country, GDP per capita, and net exports of raw materials are given in OECD database for statistics. The data for average years of education and R&D expenditure is from the World Bank education statistics database. The export volumes to the US is obtained from the UN commodity database. After excluding the countries where data is not available, 53 countries are in the sample and all the data is from the year 2010. The unit for R&D expenditure is in real 2005 million $ (PPP) per capita; the unit for GDP per capita is also in real 2005 million $ (PPP) per capita; the unit for human capital, measured by average years of education, is in years; and the unit for the export volume to the US is also in real 2005 million $ (PPP).

Table 1. List of Countries

31 Developed Countries/Regions			
Australia	Denmark	Italy	Portugal
Austria	Finland	Japan	Slovak Republic
Belgium	France	Korea	Slovenia
Canada	Germany	Luxembourg	Spain
Chile	Hong Kong	Mexico	Sweden
Croatia	Hungary	Netherlands	Turkey
Cyprus	Ireland	Norway	United Kingdom
Czech Republic	Israel	Poland	

22 Developing Countries			
Argentina	Guatemala	Lithuania	Russia
Armenia	India	Malaysia	South Africa
Bulgaria	Kazakhstan	Moldova	Ukraine
China	Kenya	Panama	Uruguay
Egypt	Latvia	Romania	

Table 2. Descriptive Statistics of Variables

Variable	Observation	Mean	Std. Dev.	Min	Max
lnpp	53	-12.37567	2.431056	-18.39956	-8.481485
lnrdp	53	-8.938022	1.842924	-13.8281	-6.665475
lngcap	53	9.452162	1.153368	6.354475	11.13832
lneduc	53	2.326418	.2082084	1.519513	2.551006
lnexpus	53	22.07628	2.313022	16.68516	26.39114
dvped	53	.6415094	.4841463	0	1
lnrddev	53	-5.004257	3.847329	-9.784782	0
li	53	-.022951	.553601	-1.0083	2.653406

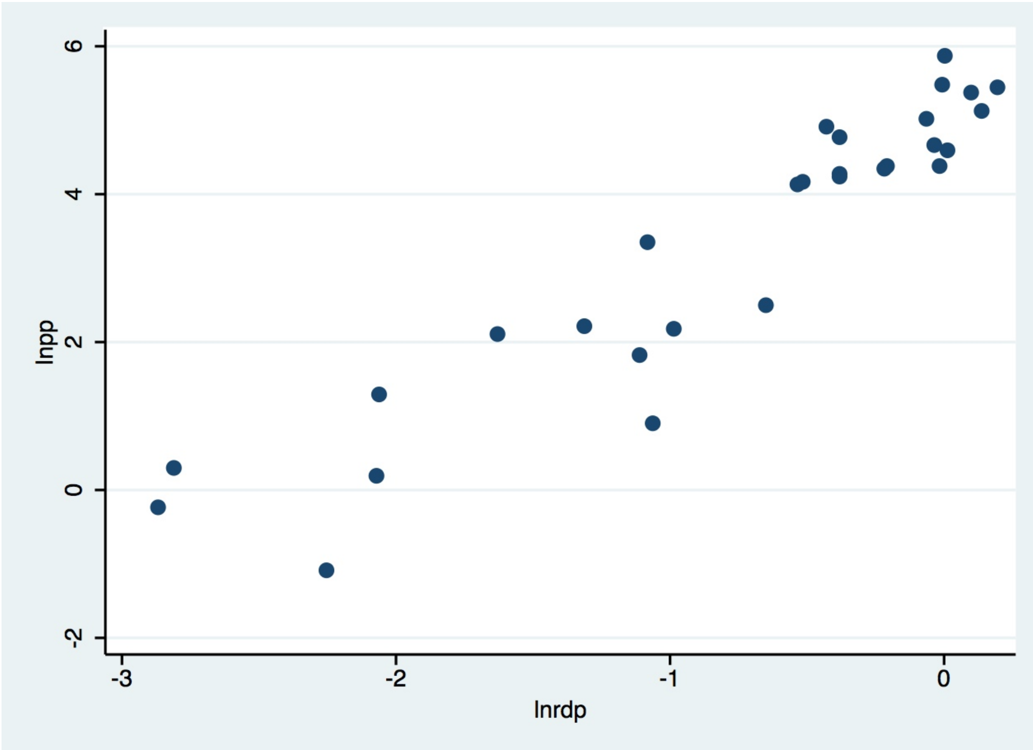

Figure 1. Simple Regression Plot of ln Patents vs ln R&D Expenditures

Table 3. Colinearity Test (Correlation Between Dependent Variables)

	lnrdp	lngcap	lneduc	lnexpus	dvped	lnrddev	li
lnrdp	1.0000						
lngcap	0.9221	1.0000					
lneduc	0.5958	0.5948	1.0000				
lnexpus	0.4477	0.3808	0.0245	1.0000			
dvped	0.8334	0.8639	0.4422	0.3292	1.0000		
lnrddev	-0.7422	-0.8046	-0.4044	-0.2737	-0.9816	1.0000	
li	-0.1005	-0.0431	0.0175	-0.0020	-0.0878	0.0689	1.0000

The models fulfills almost all of the Gauss Markov Assumptions. The first assumption that the population model is linear in parameters is followed by the fact that the models created were linear. The second assumption that the samples were randomly selected is not strictly followed since the samples were chosen by which countries had enough data to perform regression on. Because of this, there is slight bias in the data, however it is assumed that this effect is small enough to neglect. The third assumption that there is sample variation in the explanatory variable is fulfilled by the fact that not all countries had the same R&D expenditure amounts. The zero conditional mean assumption cannot be verified but is assumed to be zero based on the fact that there does not appear to be any error other than standard normal distributed error given a specific R&D expenditure amount. The fifth assumption of homoskedasticity is followed since the error is assumed to be normally distributed with the same standard error regardless of the R&D Expenditure amount.

4. Results

4.1. OLS Simple Regression

Variables	Values
Constant	-1.908**
	(0.775)
ln RDP	1.171***
	(0.085)
N	53
R-squared	0.7882
Adj R-squared	0.7841

*Significant at 10%, **5%, ***1%

Table 4. Simple Regression STATA Results

The OLS simple regression is applied to both models:

$$ln\ P = \beta_0 + \beta_1\ ln\ RDP$$

Where P is the number of patent applications per capita and RDP is R&D expenditure per capita.

The simple regressions gives the following estimation:

$$ln\ P = -1.908 + 1.171\ ln\ RDP$$

$$(0.775) \qquad (0.085)$$

n = 53, R-squared = 0.7882, adjusted R-squared = 0.7841

This result corresponds with the theoretical model for R&D: an increase in R&D input (R&D expenditure) yields an increase in technology (patents). According to the equation above, a 1% increase in R&D expenditure per capita results in 1.171% increase in the number of patents applications. The t-value is high enough, 13.78 for β_1 that we we reject the null hypothesis that $\beta_1 = 0$ at the 1% two-sided level.

4.2. OLS Multiple Regression

Variables	Model 1	Model 2	Model 3	Model 4
Constant	-11.095*	-5.434**	-9.08**	-14.231**
	(6.544)	(2.151)	(4.172)	(5.234)
ln RDP	0.940***	1.098***	1.016***	0.869***
	(0.236)	(0.931)	(0.123)	(0.073)
ln GDPcap	0.094			
	(0.353)			
ln educ	1.099		0.994	1.520
	(0.995)		(0.975)	(0.979)
ln expus	0.166	0.130*	0.157*	0.159**
	(0.080)	(0.074)	(0.079)	(0.076)
LI	-0.325			
	(0.285)			
dvped				6.699**
				(2.903)
N	53	53	53	53
R-squared	0.8100	0.8005	0.8046	0.8277
Adj R-squared	0.7897	0.7925	0.7927	0.8094

*Significant at 10%, **5%, ***1%

Table 5. Multiple Regression STATA Results

To identify the possible effects of other variables, we utilized the following equation:

$$ln\ P = \beta_0 + \beta_1\ ln\ RDP + \beta_2\ ln\ GDPcap + \beta_3\ ln\ educ + \beta_4\ ln\ expus + \beta_5\ LI$$

Where educ is the average years of education, expus is the export volume to the United States, and LI is the Leamer Index of natural resource abundance.

Regression of the equation yields the following estimation:

$$\ln P = -11.937 + 0.940 \ln RDP + 0.934 \ln GDPcap + 1.099 \ln educ + 0.166 \ln expus + 0.325\, LI$$

$$(6.54) \quad (0.236) \qquad (0.353) \qquad (0.995) \qquad (0.080) \qquad (0.285)$$

n = 53, R-squared = 0.8340, adjusted R-squared = 0.7897

The effect of R&D expenditure is found to be roughly equal to the previous regression model. The regression shows ln RDP and ln expus has statistical significance at the two sided 5% level with t values of 3.98 and 2.08 respectively while ln GDPcap, lneduc, and LI are insignificant at that level with t values of 0.27, 1.1, and -1.14 respectively. Thus, we eliminated those variables for the following restricted model.

4.3 Robustness Test (Restricted Model)

$$\ln P = -5.434 + 1.098 \ln RDP + 0.130 \ln expus$$

$$(2.151) \quad (0.093) \qquad (0.074)$$

n = 53, R-squared = 0.8005, adjusted R-squared = 0.7925

F-stat = 3.16, Critical F-stat = 2.23

Since the F-stat is higher than the critical value, the three variables ln GDPcap, ln educ and LI are jointly significant. As a result, ln GDPcap and LI were eliminated, and ln educ was used in our final model in the place of those variables:

$$\ln P = -9.081 + 1.016 \ln RDP + 0.157 \ln expus + 0.994 \ln educ$$

$$(4.172) \quad (0.123) \qquad (0.079) \qquad (0.975)$$

n = 53, R-squared = 0.8046, adjusted R-square = 0.7927

This model has a surprisingly low t value for ln educ. This can be attributed to the fact that there is very little colinearity between GDPcap, ln educ, and LI which will be shown in the later section. the t value for ln educ is 1.0195 and is not high enough to reject the null hypothesis that ln educ = 0 at the 10% level, however in this circumstance, human capital, and by extension education, should play a significant role in the amount of patents filed. Because of this, and the fact that the variable was found to be jointly significant with the other two variables, the low t value can likely be attributed to a low sample size.

4.4 Colinearity Test

To explain why lneduc, lnGDPcap and LI are insignificant, we examine the correlation between these independent variables so that high collinearity can be discovered. The result shows that lneduc is highly correlated to lnrdp, which may explain why lneduc fails to be significant. Also, dvped is very colinear with respect to lnrdp. The reason is that developed countries are more capable of spending more on R&D expenditure. In addition, lnGDPcap is almost perfectly colinear with respect to lnrdp. This can be attributed to the fact that wealthier countries can afford to invest more in R&D.

4.5 Dummy Variable Tests

Whether or not a country was developed or not could have played a role in the effectiveness of that country in creating patents. Because of this, a dummy variable test was utilized to test the effects of a country being developed or not in patent filing. The base group was set as undeveloped countries and is shown below:

$$\mathit{ln\ P} \ = \ \beta_0 + \ \beta_1\, \mathit{ln\ RDP} + \beta_2\, \mathit{ln\ educ} + \beta_3\, \mathit{ln\ expus} + \delta\, \mathit{dvped} + \delta\, \mathit{dvped} * \mathit{ln\ RDP}$$

The regression yields:

$$\underset{}{\mathit{ln\ P}} \ = \ \underset{(5.233)}{-14.23} + \underset{(0.255)}{0.651}\mathit{ln\ RDP} + \underset{(0.979)}{1.520}\, \mathit{ln\ educ} + \underset{(0.076)}{0.159}\mathit{ln\ expus} + \underset{(2.903)}{6.699}\mathit{dvped} + \underset{(0.299)}{0.734}\mathit{dvped} * \mathit{ln\ RDP}$$

n = 53, R-squared = 0.8277, adjusted R-squared = 0.8094

From this result, it is clear that a country’s development has drastic effects on the country’s ability to file patents. A developed country has a 6.699% increase in patent creation. This is significant at the 5% level with a t-value of 2.31. In addition, there seems to be a higher rate of return in R&D investment for patent creation. A 1% increase in R&D investment yields 0.734% greater increase in patent growth in developed countries compared to undeveloped countries.

Conclusion

Although growth in R&D Expenditures implies an increase in technology, technology is difficult to quantify. In this paper and in the literature (Bosch), patents filed by country is utilized to measure technology. This paper contributes to the literature by utilizing more recent data and by adding a contributing variable found in other literatures: education. education is not used as an independent variable in the original literature that this is based on (Bosch), however based on our findings in the other literature, education seems to be an essential influential variable on patent filing. Having greater education stimulates patent filing since researchers tend to be higher educated, and researchers have a higher probability of filing for patents than non researchers.

There is strong evidence linking an increase in R&D expenditures to an increase in patents filed and, by extension, growth in technology. This is based on data in 2010 and is supported by the literature as well. The result was robust to various models and the model in this paper was found to have a slightly better correlation than that in the literature due to the added variable. Overall, the findings in this report were found to be very similar to the literature and overall validates the findings in the literature. The various other independent variables: GDP per capita, natural resources abundance, and growth in education, were found to be less robust and were eliminated in the final model to be replaced by education alone.

In addition to the simple regression and multiple regression, other statistical methods such as correlation tests and dummy variable tests were used on the model. The correlation tests showed that there was significant linear correlation between whether or not the country was developed or not and the R&D expenditures. This made sense since developed countries should have more excess funds to spend on R&D. In addition, the dummy variable tests showed a clear difference between a country's patent creation on whether or not the country was developed or not. Developed countries had a much higher patent filing than undeveloped countries. This was also expected since developed countries can spend more on R&D as was found in the colinearity test. The effectiveness of R&D expenditures was found to be higher in developed countries as well. This was envisioned since developed countries have the infrastructure to better make use of R&D expenditures.

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